Table 17 is a compilation of capital cost and financing information relating to the existing federal reservoirs. To date, slightly more than 400 million dollars have been spent for their construction. In terms of 1963 dollars the figure is about 520 million. But what portion of this can be "allocated" to water quality control? The Definite Project Reports or General Design Memoranda for nine of the thirteen reservoirs included annual water quality control (WQC) benefits as part of the benefit-cost analyses (see Table 17).[67-79] The WQC benefit allowed ranged from 1.2 to 5.5 percent of the total benefits. Assuming an average value of 3.0 percent, the WQC portion of the capital cost is about 12 million dollars (15 million 1963-dollars).

Such a cost allocation can be justified only on the basis of the limited time and resources available to address this issue. Any system to allocate costs which are "joint" in the economic sense is arbitrary to some degree. However, an allocation system sensitive to the real water quality benefits generated by the reservoirs would have been more defensible. It is likely that the method employed in this study only sets a lower bound on water quality improvement costs.

ENERGETIC EXPENDITURES

Methodology

The documentation of energy expenditures involved in constructing the facilities listed in Tables 12 through 16 presented problems in that there existed no clearcut, standard methods of evaluating such costs.

A direct approach is a difficult one. It depends upon breaking up the construction of each facility into a number of components (e.g., earthwork, reinforced concrete, equipment), following as closely as possible the engineer's estimates of direct costs. The same steps would then be taken again for each component to evaluate the energies required to manufacture the various materials, shape them into specific products, transport them, and incorporate them into the component.

This approach could be directed to some very specific projects and hence has the advantage of realism. It is obvious, of course, that with about 200 municipal treatment systems, the 20 chosen industrial systems, and the 13 Corps of Engineer reservoirs constructed over a 30-year period, the task of handling the large amount of detailed information is a formidable one. Nor is all the necessary information readily available. The breakdown of the construction elements is possible only for large, aggregated classes. Direct and indirect energy requirements for these components are difficult to ascertain. An alternative approach had to be found.

Table 17. FINANCING INFORMATION FOR EXISTING FEDERAL RESERVOIRS, WILLAMETTE BASIN.

Subbasin reservoir	Estimated costs, charges, and benefits[a]: Base year	Amortization period, years	Interest rate, %	Total cost[b], 10^6 dollars	Annual charges[c], 10^6 dollars	Annual benefits, 10^6 dollars	Annual water quality benefits, 10^6 dollars	Total construction cost[d], 10^6 dollars	Annual O & M cost[e], 10^6 dollars
SANTIAM									
DETROIT	1951	50	3	62.2	2.67	3.82[f]	0.044[f]	63.1[f]	0.587[f]
BIG CLIFF	1951	50	3	9.2	0.45				
FOSTER	1962	100	2 1/2	29.6	0.98	6.38	0.152	26.0	0.615[f]
GREEN PETER	1959	50	2 1/2	68.2[g]	3.27[g]	4.13[g]	0.129[g]	57.0	
McKENZIE									
COUGAR	1956	50	2 1/2	41.5	1.86	2.91	0.070	54.3	0.211
BLUE RIVER	1963	100	2 5/8	33.6	1.02	2.38	0.028	28.9	0.052
LONG TOM									
FERN RIDGE	1939			2.6				6.0	0.166
MID FORK									
LOOKOUT POINT	1940	50	3	34.8	1.48	1.62	0.041	87.9[f]	0.673[f]
DEXTER	1951	50	3	13.1	0.65				
HILLS CREEK	1955	50	2 1/2	34.8	1.47	2.93	0.120	45.7	0.164
FALL CREEK	1961	50	2 5/8	28.8	1.12	2.38	0.131	21.1	0.091
COAST FORK									
COTTAGE GROVE	1939			2.3				2.7	0.162
DORENA	1940			4.4				14.1	0.136

[a] Data from appropriate Definite Project Reports or General Design Memoranda written prior to construction.
[b] Total investment, including recreation facilities.
[c] Includes interest, amortization, operation and maintenance, replacements, and taxes foregone.
[d] Source: "Water Resources Development by the Army Corps of Engineers in Oregon", 1973.[80] Excludes recreation facilities.
[e] Source: "Extract: Report on the Improvements in the Portland, Oregon, District", Fiscal Year 1972.[81]
[f] Combined benefits and costs of principal and reregulating dam.
[g] Includes the then planned White Bridge Reregulating Reservoir with estimated cost of $11.3 million.

Fortunately, economic analysis provides an analog which is useful in this context. Specifically, input-output (I-O) analysis is applied in this study to estimate total (direct and indirect) energy requirements. Before addressing the subject of estimating energy requirements through the input-output technique, a brief description of the nature and use of this technique in economics is necessary.

The study of the interdependency of the economics system has long been an important aspect of economic studies; but during the 1930's this study focused for the first time on the empirical relationships underlying the structure of the American economy.[82] This structure was studied by dividing the economy into a number of relatively homogeneous industrial sectors and observing the flows of goods and services among them. It is, perhaps, easiest to describe this framework by use of a simple example.

Assume a simple economy with four sectors: Agriculture (I), Manufacturing (II), Construction (III), and Energy (IV). The fundamental input-output relationships are presented below.

	I	II	III	IV	Final Demand (y_i)	Total Output (X_i)
I	x_{11}	x_{12}	x_{13}	x_{14}	y_1	X_1
II	x_{21}	x_{22}	x_{23}	x_{24}	y_2	X_2
III	x_{31}	x_{32}	x_{33}	x_{34}	y_3	X_3
IV	x_{41}	x_{42}	x_{43}	x_{44}	y_4	X_4

The crucial elements in this table are the X_i : 's on the left side. They represent the dollar value of the flow of gooas and services from the sector listed on the left of a particular cell to that listed as the column heading. Thus x_{12} represents the value of goods and services flowing from the agricultural to the manufacturing sector. These elements are referred to as "interindustry demands" because they reflect the requirements which one sector places on the production of other sectors in order to meet its own production goals.

The elements y_i are "final demands". They reflect largely household consumption, exports , investments, and government purchases. Interindustry demands plus final demands must equal a sector's total output (X). Thus, the following equation can be written for sector I, for example:

$$x_{11} + x_{12} + x_{13} + x_{14} + y_1 = X_1$$

Or, in general terms, the equation is:

$$\Sigma x_{ij} + y_i = X_i \qquad (1)$$

There are two ways of obtaining the numerical estimates of the x_{ij}'s. First, one can observe the transactions in dollar terms of the goods and services flowing from one sector to another to determine the inter-industry demands. Secondly, one can make use of the assumption that input requirements of a sector are directly proportional to that sector's output. These input requirements are technologically fixed and can be derived from knowledge of technical production relationships. Equation (2) can be written as:

$$x_{ij} = a_{ij} X_j \qquad (2)$$

The terms of our example, x_{12} (the value of goods and services flowing from the agricultural to the manufacturing sector) is a function of the level of output of the manufacturing sector (X_2) and the technical coefficient, a_{12}.

It should be noted here that I-O analysis uses linear approximations to describe economic interactions. Thus large changes in one or more sectors could significantly alter the coefficients employed. Other shortcomings of using the input-output technique in this application are those generally attributable to the use of this mode of analysis. These are discussed elsewhere and are well-known.[83] They are not especially limiting in this application. The reader is cautioned, however, that the fixity in technology assumption, which this analysis employs, would become especially troublesome when predictions about energy use are made in a situation when energy price relationships are expected to change. In contrast, energy prices were relatively stable during the period of this analysis.

Equation (2) can be substituted into equation (1) to obtain:

$$\Sigma\, a_{ij} X_j + y_i = X_i \qquad (3)$$

Returning briefly to the subject of the interdependent nature of the economic system, it is apparent from the transactions table and from equation (1) that a change in output of any sector will cause the output of other sectors to change. This is because the interindustry demands faced by these sectors will be altered. These output changes will again cause outputs to respond in other sectors. What will be the extent of these output changes? Solving equation (3) for output provides the answer.

In matrix notation equation (3) is written as

$$AX + Y = X$$

where, for this example,

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \qquad X = \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} \qquad Y = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix}$$

$$X - AX = Y \text{ and}$$

$$X = (I-A)^{-1}\,Y \tag{4}$$

where I is an identity matrix.

Designating the elements of $(I-A)^{-1}$ as c_{ij}, the matrix for this example can be written as:

$$(I - A)^{-1} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix}$$

In this example, the interpretation of the c_{ij}'s is very important. Where a_{12} yielded the direct output requirement from sector I as the output of sector II changed by one unit, c_{12} yields the total (direct and indirect) output requirement from sector I as the output from sector II changes by one unit. The latter accounts for all interindustry relationships in the economy.

This brings us almost to the solution of the problem. Postulating that, because of increased water quality requirements in the Willamette River System, the output of the construction sector (III) increases by one dollar, then the coefficient c_{43} will yield the estimate of the output response required from the energy sector (IV).

Only one problem remains. The predicted output response of sector IV is in value terms (dollars); the interest here is in predicting the response in terms of physical units (Joules). It would be a simple matter of dividing the value estimate by the price of energy to obtain the response in physical units. It is known, however, that energy is sold to various sectors at different prices. (This point and the prices actually used in the calculations are taken from Herendeen.[84]) To estimate the number of physical units of energy required to serve a change in the final demand of the construction sector, Δy_3, a more complicated procedure must be employed.

Equation (4) allows us to write

$$\Delta X = (I - A)^{-1}\,\Delta Y \quad . \tag{5}$$

Equation (5) can be written as

$$\begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix} \begin{bmatrix} \Delta y_1 \\ \Delta y_2 \\ \Delta y_3 \\ \Delta y_4 \end{bmatrix} = \begin{bmatrix} \Delta X_1 \\ \Delta X_2 \\ \Delta X_3 \\ \Delta X_4 \end{bmatrix} \tag{6}$$

As we assumed the final demand to change in the construction sector only, $\Delta y_1 = \Delta y_2 = \Delta y_4 = 0$. According to equation (6) output changes in the economy then become

$$\begin{aligned} \Delta X_1 &= c_{13}\Delta y_3 \\ \Delta X_2 &= c_{23}\Delta y_3 \\ \Delta X_3 &= c_{33}\Delta y_3 \\ \Delta X_4 &= c_{43}\Delta y_3 \end{aligned}$$

These ΔX_i's represent the total value of output change associated with Δy_3 (a change in the final demand of the construction sector).

Of primary interest is the output change of the energy producing sector (ΔX_4). ΔX_4 represents the change in the value of output of the energy producing sector. Assuming that prices vary according to the sector to which Sector IV sells its output, then it becomes necessary to know how ΔX_4 is composed. In other words, the changes in the values of output flowing from sector IV to each of the sectors of the economy must be known. To estimate these flows equation (2) is utilized to write:

$$\Delta x_{ij} = a_{ij}\ \Delta X_j \tag{7}$$

The right side of equation (7) is the matrix:

$$\begin{bmatrix} a_{11}\ \Delta X_1 & a_{12}\ \Delta X_2 & a_{13}\ \Delta X_3 & a_{14}\ \Delta X_4 \\ a_{21}\ \Delta X_1 & a_{22}\ \Delta X_2 & a_{23}\ \Delta X_3 & a_{24}\ \Delta X_4 \\ a_{31}\ \Delta X_1 & a_{32}\ \Delta X_2 & a_{33}\ \Delta X_3 & a_{34}\ \Delta X_4 \\ a_{41}\ \Delta X_1 & a_{42}\ \Delta X_2 & a_{43}\ \Delta X_3 & a_{44}\ \Delta X_4 \end{bmatrix}$$

The technical coefficients and the ΔX_i in the above matrix are known. Its bottom row represents the dollar values of deliveries from the energy sector to each of the other sectors of the economy to satisfy the change in final demand faced by the construction sector (ΔY_3). If P_{41}, P_{42}, P_{43}, and P_{44} are the prices at which energy is sold to sectors I, II, III, and IV, respectively, then the total output change in physical units required from the energy sector (ΔE_4) to meet the change in final demand of the construction sector (ΔY_3) can be obtained using equation (8):

$$\Delta E_4 = \frac{a_{41}\ \Delta X_1}{P_{41}} + \frac{a_{42}\ \Delta X_2}{P_{42}} + \frac{a_{43}\ \Delta X_3}{P_{43}} + \frac{a_{44}\ \Delta X_4}{P_{44}} \tag{8}$$

The I-O model employed broke the economy up into 362 sectors, five of which were energy suppliers (coal, crude oil and gas, refined petroleum, electricity, and natural gas).[84]

The use of the I-O energy model allowed the researchers to calculate the "direct" energy requirement per dollar of sales in a particular sector and the "indirect" energy needs of all the other sectors combined required to support a dollar of sales in the first industry. Figure 17 will help clarify the differences between "direct" and "indirect" requirements.

As can be seen from the figure, "direct" energy sales included only those made directly by the five energy sectors to another sector (construction in this case). "Indirect" energy sales were those made by the five energy sectors to any other for its support of the industry in question. It should be noted that the "indirect" energies included only operational energies and excluded capital energies. Referring to Figure 17, this means the energy required to build the steel mill is excluded; only the energy required to make the steel is included. It is felt that negligible error results from this practice.[85]

A problem involved with using this method is the exclusion of energy costs of imports to the economy, which introduced about a ten percent error. The entire procedure yielded answers that were felt to be within fifty percent of the actual value.[85]

Results

The I-O-energy model approach to converting dollar costs of construction to energy costs was employed on the expenditures discussed earlier in this chapter. Table 18 lists the values of the coefficients used in the conversion process. The coefficients are energy conversions for the particular category of construction which includes dams and sewerage works.

Table 19 presents the results of applying the coefficients to the construction costs of the facilities previously discussed.

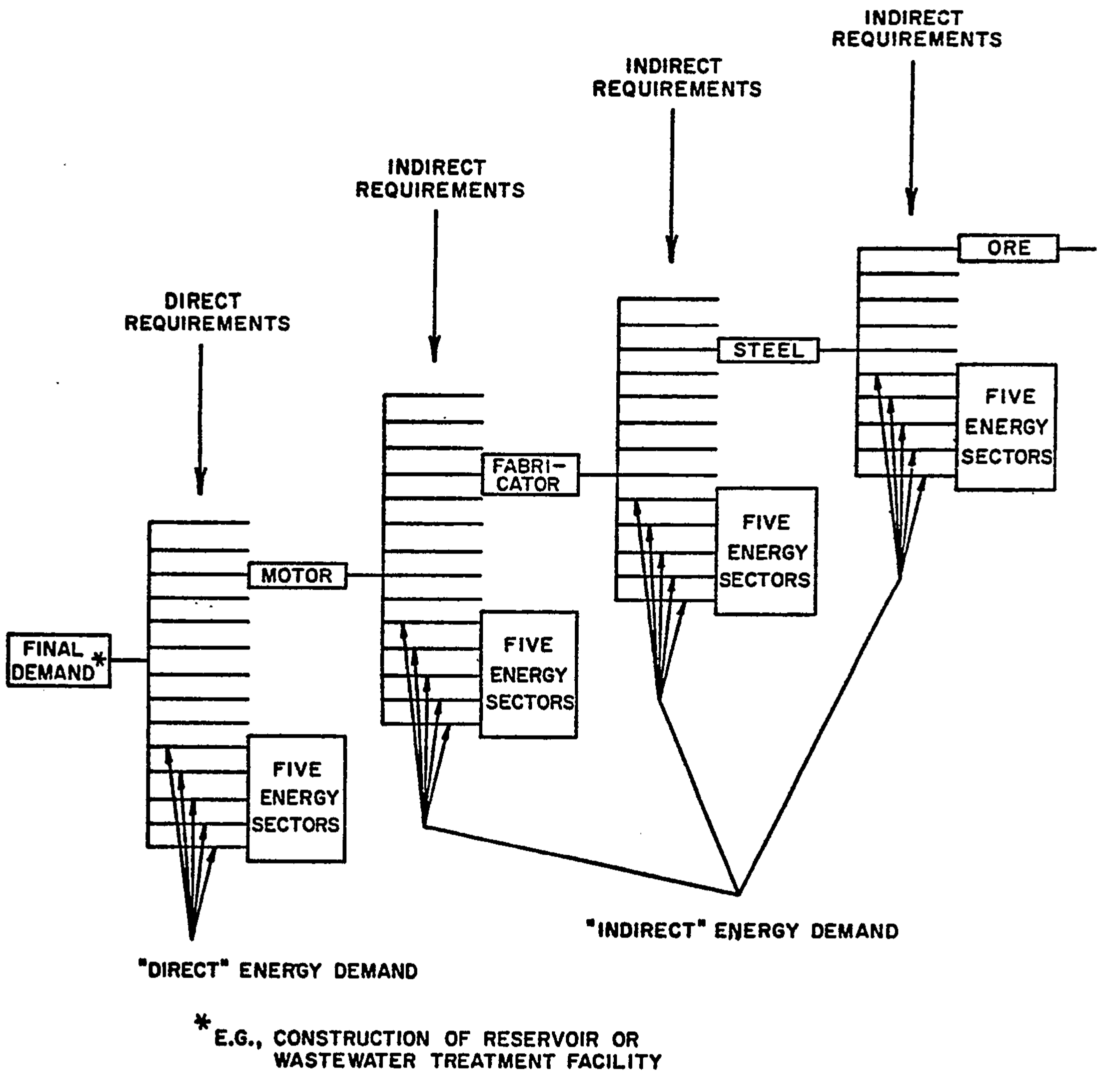

Figure 17. Input-output-energy model energy flows.

Table 18. COEFFICIENTS USED IN CONVERTING CONSTRUCTION DOLLARS TO ENERGY VALUES[a]

Energy	Coefficients, Mega Joules (MJ)/dollar[b]	
Type	Direct	Total
Coal	0.000	25.996
Crude oil and gas	0.000	47.008
Refined petroleum	8.560	26.644
Electricity	0.211	3.631
Natural gas	0.410	21.258
Total	9.181	124.537

[a] Source: reference 84, construction sector 11.05; based on 1963 dollars.

[b] 1 MJ = 948 British Thermal Units (BTU).

Table 19. ENERGY COSTS OF CONSTRUCTING THE WATER POLLUTION CONTROL FACILITIES OF THE WILLAMETTE BASIN

Facility classification[a]	Construction costs, 1963 dollars	Direct energy requirement, Tera Joules (TJ)[b]	Total energy requirement, TJ[b]
Municipal facilities			
Treatment plants	74,000,000	680	9,200
Interceptors	41,000,000	380	5,100
All facilities	120,000,000	1,100	15,000
Industrial facilities	34,000,000	310	4,200
Reservoirs			
Total	520,000,000	4,800	65,000
3% - WQC[c]	15,000,000	140	1,900

[a] As defined; see text for full description of facility classification.

[b] 1 TJ = 948 x 10^6 BTU.

[c] 3% allocated for water quality control.

Verification

A verification of the results of applying the I-O-energy model concept to the construction of the water pollution control facilities was carried out and the procedure is outlined here. The direct construction energy requirements for one recently completed activated sludge wastewater treatment plant and for two reservoirs, Green Peter Lake, having a concrete dam and power production facilities, and Blue River Lake, having two earth filled dams and no power producing facilities, were investigated in detail. The results of the earthwork energy (i.e., energy per unit of excavation and backfill) calculations for the activated sludge plant were then applied to ten other treatment facility construction projects in an effort to expand the verification.

The appropriate findings of the report "Energy Use in the Contract Construction Industry"[86] were also used as a means of checking the direct construction energy requirements estimated by the I-O-energy methodology. The results of this report are based upon estimated energy requirements in different construction categories (e.g., heavy construction, sewerage works) as a function of a project's monetary value. The report also allows the user to estimate the energy needs for various items (e.g., earthwork) within each category. It should be noted that this report is not for contract estimating purposes but rather for evaluating the effects of various energy supply situations on different construction sectors.

Table 20 presents comparisons of the I-O-energy methodology results, the values arrived at using the report[86] mentioned above, and the estimates made by the researchers for the three projects investigated in detail. Also included in Table 20 is the energy required to manufacture just the cement and the reinforcing steel that went into the projects.

Table 21 is a comparison of direct construction energies of 10 treatment plants utilizing the three methods discussed above. Also included is the energy required to manufacture the cement and reinforcing steel that went into the facilities.

Several important notes should be made regarding the comparisons which Tables 20 and 21 present. One, the energy need estimated using the I-O-energy model approach is consistently lower than the requirement estimated using the construction energy study.[86] This may be true for several reasons including: 1) the report is based upon 1973 costs while the I-O-energy methodology is founded upon a 1963 transactions table of the economy--construction has, in general, become more energy intensive with time; 2) the energy pricing portion of the I-O-energy method work, based upon national data, may have priced energy supplied to the construction sector too high for use in the Willamette Basin--

Table 20. COMPARISON OF DIRECT CONSTRUCTION ENERGY REQUIREMENTS OF THREE PROJECTS

Project Energy type	Direct energy requirement, TJ[a]				Materials[d] energy, TJ[a]
	Via I-O-energy methodology	Via reference 86		Via direct calculation[c]	
		Total	Appropriate items[b]		
Green Peter Lake					
Refined petroleum	488	779	430	236	
Electricity	12	41	0	71	
Natural gas	23	0	0	0	
Total	523	820	430	307	780
Blue River Lake					
Refined petroleum	247	534	290	396	
Electricity	6	28	0	1	
Natural gas	12	0	0	0	
Total	265	562	290	397	90
Activated sludge plant					
Refined petroleum	15	35	12	7.3	
Electricity	0.3	2	0	0	
Natural gas	0.7	0	0	0	
Total	16	37	12	7.3	35

[a] 1 TJ = 948 x 10^6 BTU.

[b] Appropriate items selected to facilitate comparison with direct calculation: earthwork and concreting for Green Peter and Blue River Lakes; earthwork only for activated sludge plant.

[c] For earthwork and concreting at Green Peter and Blue River Lakes; earthwork only for activated sludge plant.

[d] Energy required to manufacture just cement and reinforcing steel included in project.

Table 21. COMPARISON OF DIRECT CONSTRUCTION ENERGY REQUIREMENTS OF WASTEWATER TREATMENT PLANTS

Plant	Direct energy requirement, TJ[a]				Materials[b] energy, TJ[a]
	Via I-O-energy methodology	Via reference 86		Earthwork via direct calculation	
		Total	Earthwork		
1	5.1	12	3.7	0.36	5.7
2	14.0	29	9.1	1.1	27.
3	4.5	11	3.3	0.09	5.3
4	7.2	17	5.2	0.19	6.5
5	11.0	24	7.4	0.36	12.
6	8.6	13	4.1	0.13	5.5
7	10.0	23	7.1	0.83	16.
8	7.7	17	5.4	0.45	14.
9	25.0	52	16.	0.93	c
10	5.0	12	3.7	0.29	5.5

[a] 1 TJ = 948 x 10^6 BTU.

[b] Energy required to manufacture just cement and reinforcing steel included in project.

[c] Not available.

thus the energy/dollar conversion coefficient might be low; and 3) the construction energy report[86] is based upon estimating energy needs in construction--it is possible that overestimating may have occurred.

Two, note how the direct calculations compare with the values of the first two methods. For the two reservoirs in Table 20 the major energy uses--excavation and concrete work--were considered. For the activated sludge plant, all the major earthwork items were considered, but concreting was excluded. The direct calculations for these three jobs show fairly good correlation with the other methods. For the 10 treatment plants in Table 21, however, it can be seen that the directly calculated earthwork energy values are quite low compared with the values of the other methods. This is because only the excavation and backfill earthwork items were checked. (The inclusion of energy required to make concrete, i.e., transport of aggregate from borrow to batch plant, batch plant operation, and ready-mix transport, would not significantly increase the reported values.) This poor verification may have occurred for several reasons including: 1) general excavation and backfill require quite low energy inputs per unit of work compared to other earthwork items (e.g., riprap work, offsite disposal of materials); 2) an energy requirement per unit of estimated excavation and backfill was applied only once, while it is not uncommon to move the same earth several times (e.g., opening up a trench more than once to put in various utilities); and 3) efficiencies may have been much lower than that assumed in the calculation, i.e., idling equipment may utilize much more fuel than reckoned.

Finally, note the large amount of energy required to produce just the cement and reinforcing steel that goes into the facilities in Tables 20 and 21. Considering the many products and pieces of process equipment that make up these water pollution control facilities, it is not difficult to see why the total energy coefficients of Table 18 are so much larger than the direct coefficients.

Direct energy requirements for interceptor construction were not investigated, but a relatively high portion of contract amounts in this type of building would be for earthwork. Thus, direct energy requirements would be relatively high.

SECTION VIII

OPERATION AND MAINTENANCE EXPENDITURES

MUNICIPAL SYSTEMS

0 & M costs of municipal wastewater treatment systems as well as those of private sewage systems for the period 1973-74 were investigated. Municipal data was gathered from a survey of monthly reports submitted to the DEQ by plant operators, a review of recent EPA 0 & M audits, and the results of a WRRI treatment plant survey. Most of the information gained is tabulated in the Appendix.

To arrive at the total annual dollar and energy expenditures required to operate and maintain municipal treatment works in the Willamette Valley, considerable estimating was required. Different methods of estimating were used in various areas and the appropriate discussions are to be found in the sections below. Regression analyses were carried out where statistical significance existed.

0 & M costs were researched for the interceptor portion of municipal collection systems. Operational costs are mainly restricted to those of running pump stations and depend significantly upon topography and flow variation. Maintenance costs for cleaning, inspection, and normal repair are low; most collection system maintenance needs are for the smaller sewers "upstream" of the interceptors. More detail is given in subsequent paragraphs.

Treatment Facilities

Electrical Requirements --- Large amounts of electrical energy are used in the treatment of sewage, mainly for pumping and aeration, where employed. Information relating to periodic electrical usage was gathered. In those instances where a periodic dollar expenditure was known but an energy consumption figure was lacking, the "National Electric Rate Book"[87] was employed to estimate the missing figure.

Figure 18 is a plot of unit cost as a function of daily usage. Figure 19 relates consumption to average flow; the variation on energy intensiveness for differing processes is very noticeable. Figures 20 and 21 present electrical unit requirements as a function of total pollutant removal per day for 5-day Biochemical Oxygen Demand (BOD_5) and suspended solids, respectively. The variation between processes is also noticeable here.

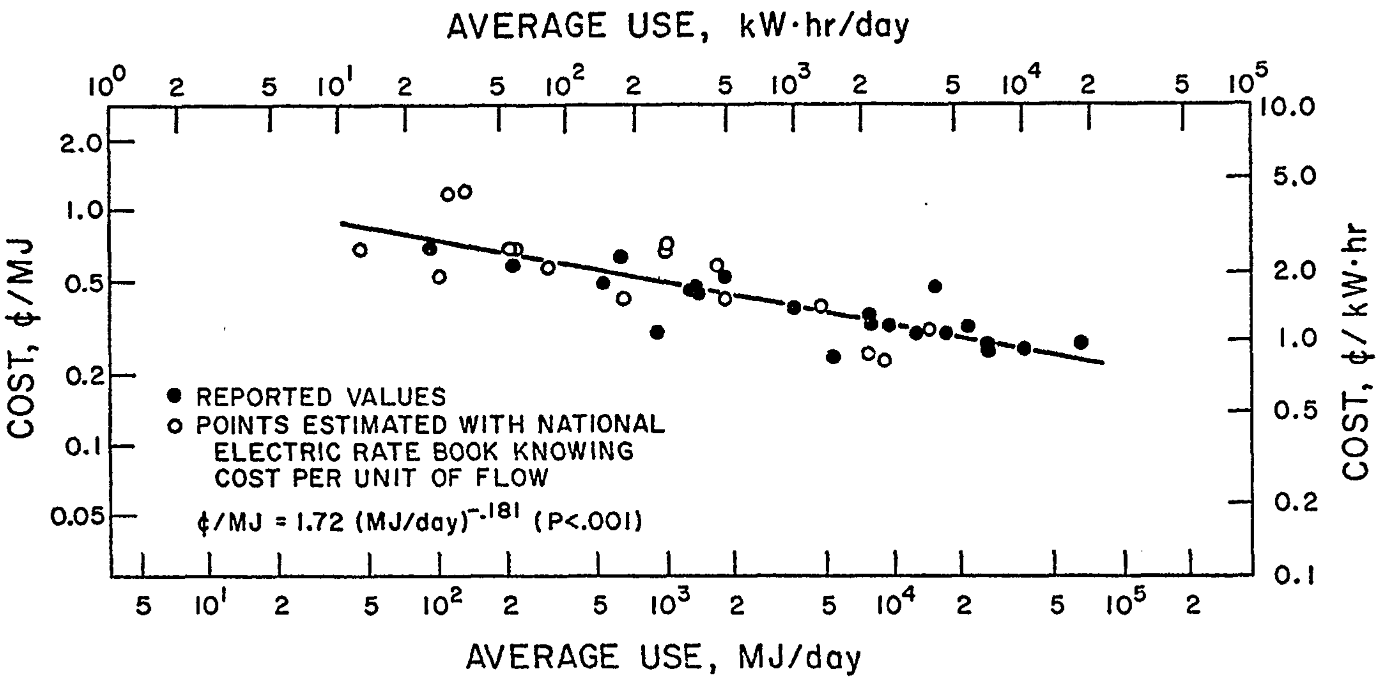

Figure 18. Electrical unit cost vs. daily consumption.

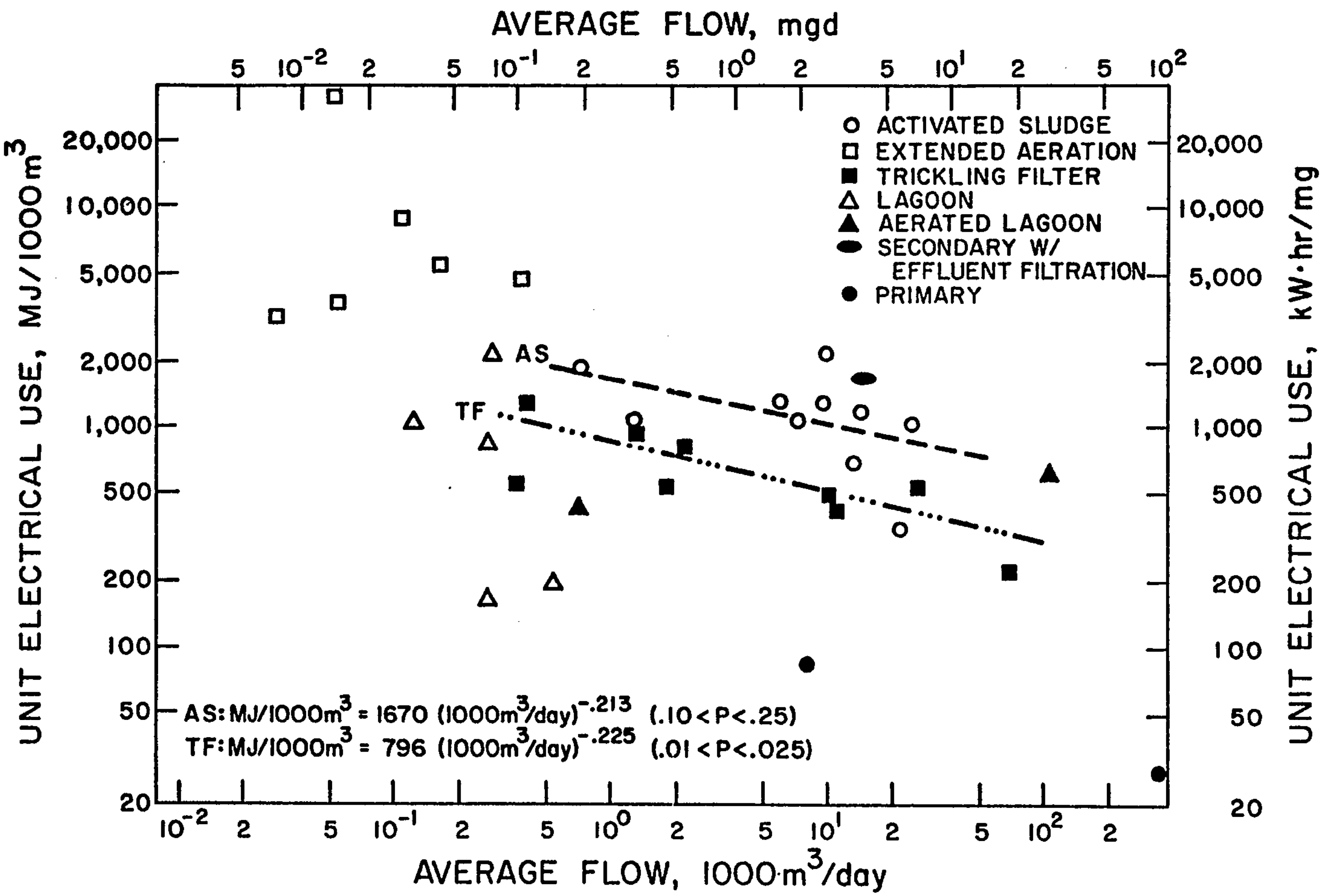

Figure 19. Electrical use vs. wastewater flow.

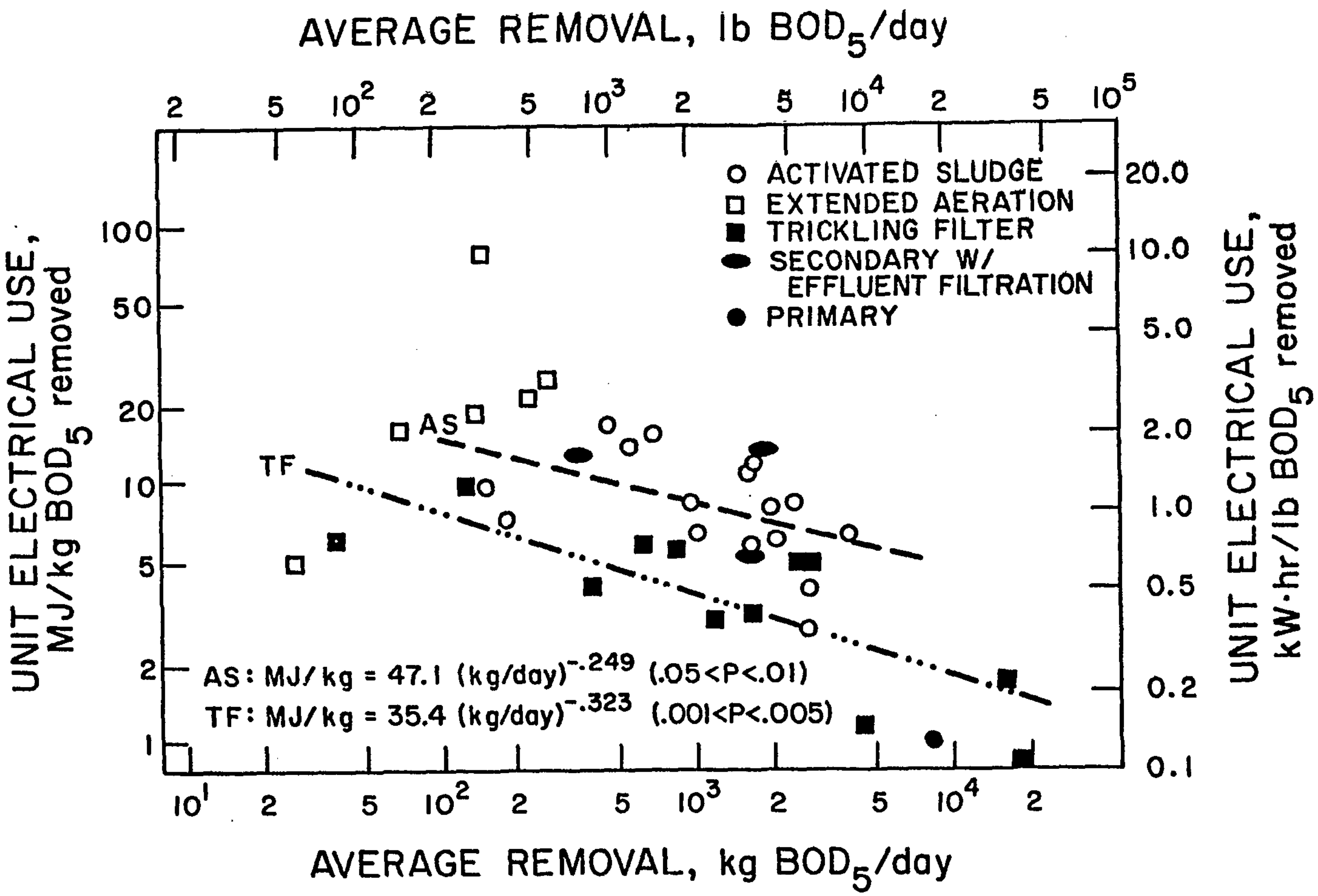

Figure 20. Electrical use vs. BOD_5 removal.

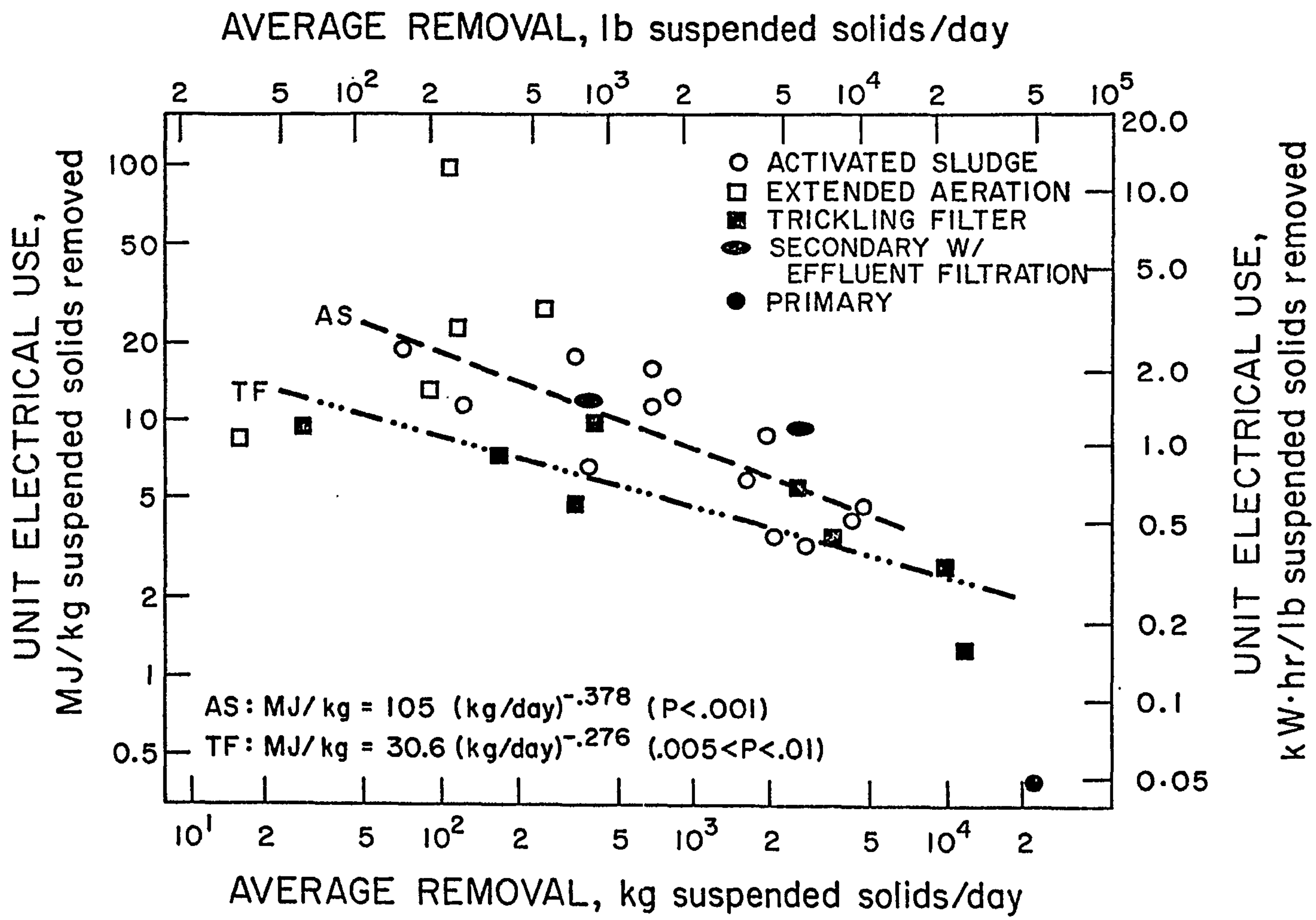

Figure 21. Electrical use vs. suspended solids removal.

The work of Smith[88] was utilized to check the results. His calculations range from 10 to 40 percent below the values presented in Figure 19. Smith's work is based upon summing the calculated electrical requirements for the motors which operate the various pieces of plant equipment, where as Figure 19 presents total requirements without looking at individual machinery. The different methodologies may, in part, explain the differences.

Another use of Smith's work lies in apportioning energy costs between different levels of treatment. At a conventional trickling filter plant the primary treatment units, including capacity for sludge processing accounts for approximately 70 percent of the total energy requirements. At a conventional activated sludge plant, because of the aeration requirements and increased sludge handling capacity, primary treatment accounts for about 35 percent of the total energy use. Effluent filtration, which is employed at several treatment facilities in the valley, adds 25 and 12 percent for trickling filter and activated sludge plants, respectively.

Using Figures 18 and 19 to estimate missing unit cost and energy requirements , respectively, the total annual energy expenditure for wastewater treatment in the Basin was about 180 tera Joules (TJ) (51 x 10^6 kilo-Watt·hours (kW·hr)), an average of 0.50 TJ/day (140,000 kW·hr/day). This amounts to approximately one quarter of one percent of the total Willamette Valley electrical use. Reported dollar costs varied from \$0.13/1000m^3 (\$0.51/million gallons (mg)) at a large primary treatment plant to \$60/1000m^3 (\$230/mg) at a small package extended aeration plant. Secondary treatment plants with flows of 3,800 to 110,000m^3/day (1.0 to 30 mgd) generally had electrical costs on the order of \$0.80 to \$6.60/1000m^3 (\$3 - \$25/mg). The total annual electrical cost for municipal wastewater treatment for the Willamette Valley was about \$600,000 for the 1973-74 period.

Before leaving this section on electricity it would be well to ask two questions. First, what are the direct electrical energy requirements of primary treatment, or, said another way, what savings could be realized if secondary treatment was not employed? Allowing lagoons and extended aeration plants to remain unchanged, a "return" to primary treatment at all trickling filter and activated plants would allow a savings of approximately 0.22 TJ/day (62,000 kW·hr/day) or nearly 45 percent. Second, what would be the direct energy impact if all activated sludge systems were replaced by trickling filtration systems? This "change" would bring about savings of about 0.15 TJ/day (41,000 kW·hr/day) or nearly 30 percent. Of course, the environmental impacts of the effluents would be altered in either case but it is clear that secondary treatment requires a significant resource allocation, the environmental impact of which is not normally considered.

Chemicals --- Chlorine is the major chemical employed in wastewater treatment in the Willamette Valley. All domestic sewage treatment plants employ chlorine as a disinfectant, as does one pulp and paper mill where coliform growth is a problem. A variety of other chemicals, such as settling aids or sludge dewatering agents, are occasionally used. The major thrust of investigation in this area (especially energy costs) was aimed at chlorine. Thus, most of the following discussion concerns its manufacture and use.

Chlorine production --- Chlorine is produced in conjunction with caustic soda and hydrogen by electrolytic action on a solution of sodium chloride:

$$2H_2O + 2NaCl \rightarrow Cl_2 + 2NaOH + H_2 .$$

For each part of chlorine, 1.14 parts, by weight, of sodium hydroxide and 0.028 parts of hydrogen are produced.

The two main types of electrolytic cells used commercially are the diaphragm and mercury cells. The past two decades saw a rapid growth in the use of the mercury cell which is capable of producing a higher quality caustic soda than is the diaphragm type. However, the present stringent environmental controls required for mercury have brought this cell's future growth to a standstill; all new plants being planned in this country are of the diaphragm type and technological improvements for it are being intensively sought.[89]

Generally, the diaphragm cell consists of alternating graphite anode plates and asbestos-impregnated steel screen cathodes. The asbestos acts as a membrane, allowing the salt brine to flow to the cathode and preventing back migration of the sodium and hydroxyl ions. Hot, wet chlorine gas is generated at the anode, taken off the top of the cells, cooled with water in counter current packed towers, dried with sulfuric acid, and then compressed and sometimes liquified. A solution ten to fifteen percent in caustic and salt is continuously withdrawn from the bottom of the cell. The solution is concentrated to 50 percent or higher in caustic while most of the salt is precipitated out and used to recharge the cell.[89,90,91]

In the mercury cell chlorine is again formed at the anode; however, a sheet of flowing mercury serves as the cathode. The sodium ions from the brine form an amalgam with the mercury, which is pumped to a separate tank containing water. Here the sodium reacts with the water to form the sodium hydroxide and hydrogen. The caustic solution is much purer than that from the diaphragm cell and much more concentrated, thus requiring less evaporation equipment.[89,90,91]

Energy consumption in chlorine production --- Due to the electrical requirement for cell operation and heat needed in the concentration of the caustic solution, the production of chlorine and caustic is highly energy intensive. Table 22 gives two estimates for energy requirements for their production.

Chemical usage in the Willamette Valley --- A 1967 Bonneville Power Administration (BPA) study[91] estimated chlorine usage for wastewater disinfection in the Pacific Northwest at 1.5 kilograms (kg) (3.2 pounds (lbs)) per person per year. Assuming $0.38 m^3$ (100 gallons) of sewage per person per day, this works out to about 10 kg/ $1000 m^3$ (85 lb/mg). The results of the OSU WRRI sewage treatment plant questionnaire showed that more reasonable figures for the Willamette Valley are 5.3 kg/$1000 m^3$ (44 lb/mg) and 7.9 kg/$1000 m^3$ (66 lb/mg) for plants treating more or less than 3,800m^3/day (1 mgd), respectively. These figures put average chlorine use at 5 to 8 mg/l of raw sewage.

Using the actual values reported in the WRRI questionnaire and estimating missing figures employing the 5.3 kg/$1000 m^3$, 7.9 kg/$1000 m^3$, and $0.38 m^3$ sewage/capita/day values stated above, chlorine consumption for wastewater treatment was approximately 1,800,000 kg (2,000 tons) in 1973. The energy requirement for this amount of chlorine, based on the data in Table 22, could range from 69 to 85 TJ (7.6 to 9.3 x 10^6 kW·hr) depending on the method of production. This amount is equal to between 40 and 45 percent of the electrical needs of all the municipal treatment plants! The cost of chlorine ranged from about $0.02/kg ($0.05/lb) to over $0.09/kg ($0.20/lb). Unit costs varied from $0.50 to $10/$1000 m^3$ ($2 to $40/mg), excluding a few plants with very high costs. The total annual chlorine expenditure in the 1973-74 period was about $260,000.

It should be noted that reported (WRRI questionnaire) residual chlorine values in plant effluents range to over ten times the 1.0 mg/l (after 60 minutes detention) requirement of the DEQ. Obviously substantial savings could be realized in this area. Also, some of the ecological problems associated with chlorination (e.g., toxicity) could be reduced if chlorine application were more closely monitored.

As stated above chlorine is the main chemical used for municipal wastewater treatment. At an individual plant, however, chlorine may account for as little as 10 percent of total chemical costs, although for most plants the figure is in the 70 to 100 percent area. As estimated range for total annual chemical costs is $300,000 to $350,000.

Table 22. ENERGY CONSUMPTION IN CHLORINE MANUFACTURE[a]

Input	Requirements/1,000 kg (2,204.6 lbs)	
	Diaphragm Cell	Mercury Cell
Process Steam		
kg	5,250	245
(lbs)	(11,600)	(540)
Equivalent GJ[b]	16.4	0.77
(Equivalent BTU)[b]	(15.5×10^6)	(0.73×10^6)
Electricity		
GJ[c]	30.5	37.3
(kW·hr)	(3,350)	(4,100)
Total		
GJ	46.9	38.1
(kW·hr)	(5,150)	(4,180)
(BTU)	(44.4×10^6)	(36.0×10^6)

[a] Data from reference 89,
[b] Based on 2950 British Thermal Units (BTU)/kg steam and 1,054.8 J/BTU.
[c] Based on 50% self generated electricity: overall 9.08×10^6 J/kW·hr.

Auxiliary Fuels --- The use of gaseous and liquid fuels in municipal wastewater treatment was researched, but very few data exist on this subject. Fuel use is primarily limited to the heating of anaerobic digesters during periods of low methane production. Usable information on digester gas production was reported by only seven plants. A correlation of gas production to flow and BOD_5 and suspended solids removals was computed and the results are summarized as follows: 22-90m^3 gas/1000m^3 sewage (2,900-12,000 ft^3/mg); 0.14-0.61m^3 gas/kg BOD_5 removed (2.3-8.5 ft^3/lb); and 0.14-0.70m^3 gas/kg suspended solids removed (2.3-9.7 ft^3/lb).

Information existed about auxiliary fuel use at six of these seven plants. Assuming a heat value of 22 MJ/m^3 of gas (600 BTU/ft^3), the methane gas produced at these six plants accounted for 81 - 99 percent of the heat requirement. Auxiliary requirements at these six plants ranged from 4.5 - 160 MJ/1000m^3 wastewater (0.016 - 0.58 x 10^6 BTU/mg). A dozen other plants, where digester performance data was lacking, had requirements from 28 - 2,800 MJ/1000m^3 wastewater (0.10 - 10 x 10^6 BTU/mg).

It is difficult to put a figure on the total basin auxiliary fuel requirement; but, assuming a value of 100 MJ/1000m^3 wastewater (0.36 x 10^6 BTU/mg) to estimate missing figures, the needs of those plants having anaerobic digesters (some have aerobic digestion and at least one employs vacuum filtration on its waste activated sludge) would be approximately 33 TJ/year (31 x 10^9 BTU/year), less than one-tenth of one percent of the gas supplied to the Willamette Valley.

Labor and Maintenance --- Labor and maintenance costs were correlated to flow and plant type and the results are presented in Figures 22 and 23. Labor accounted for approximately 60 percent of total 0 & M costs; maintenance ranged from 5 to 15 percent of the total.

Total Operation and Maintenance --- Figure 24 is a presentation of total 0 & M costs for municipal wastewater treatment as related to average daily flow and type of treatment system. Reported unit costs varied from \$6.1/1000m^3 (\$23/mg) to \$340/1000m^3 (\$1,300/mg). Total annual costs for the 1973-74 period amounted to approximately \$6,400,000.

Other Considerations --- Before leaving this section on municipal wastewater treatment, two other aspects, the costs of which are included under total 0 & M, will be discussed.

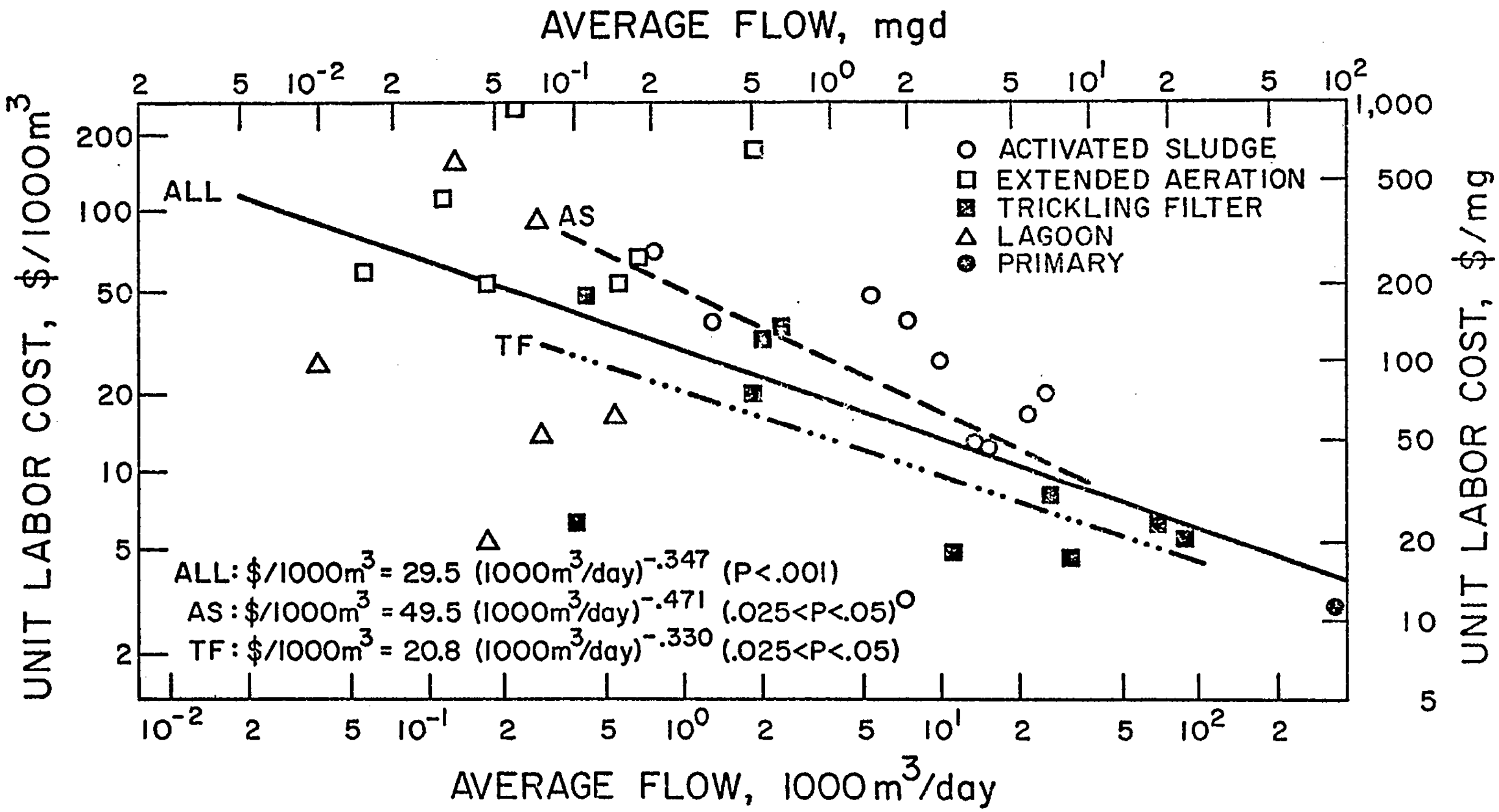

Figure 22. Labor cost vs. flow.

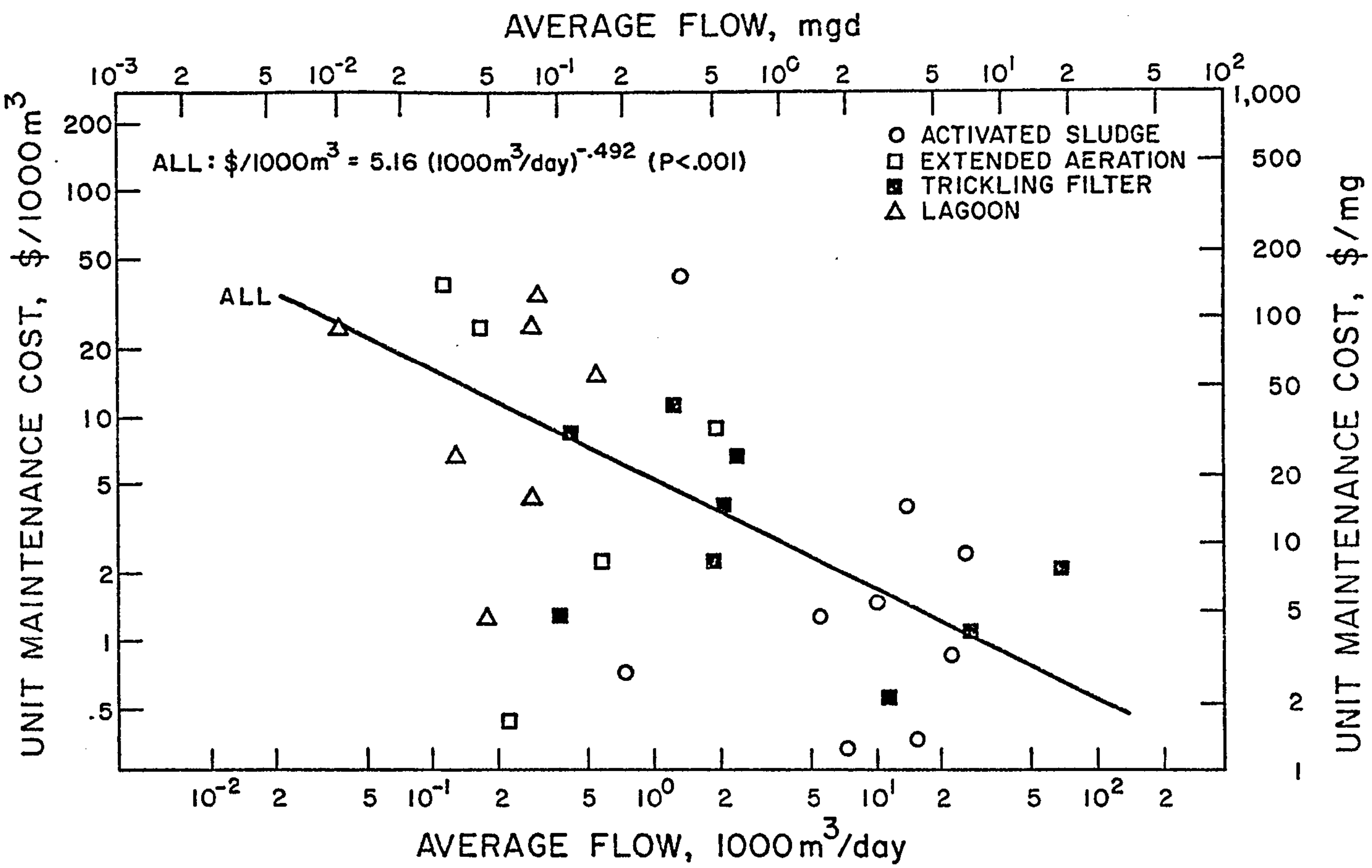

Figure 23. Maintenance cost vs. flow.

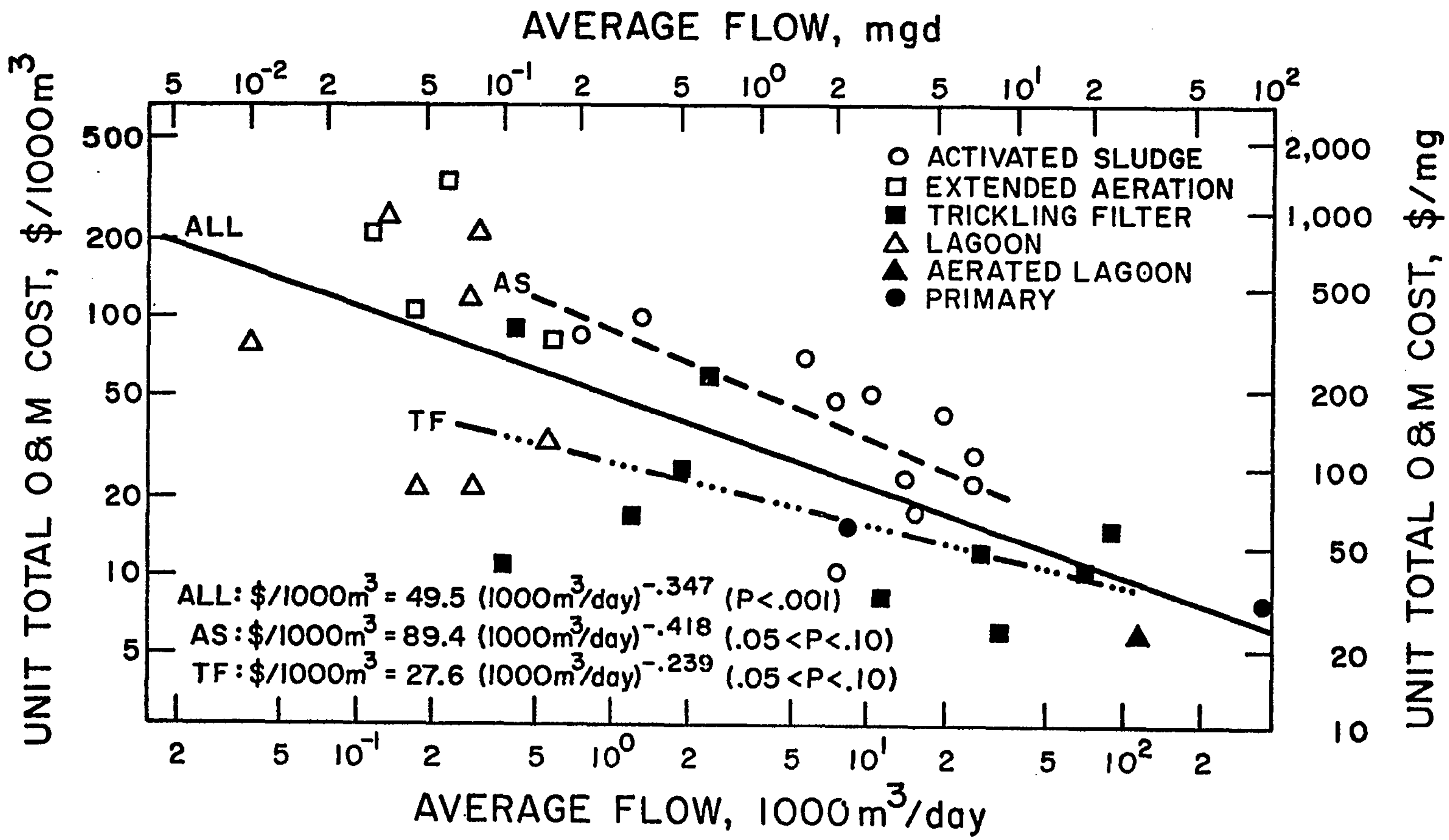

Figure 24. Total operation and maintenance cost vs. flow.

Energy cost of transportation --- The cost of transporting materials which support plant operation is reflected in the materials' purchase price, and this purchase price includes the direct energy needs of transportation. As an example, the energy requirement for chlorine supply was estimated. Using a unit energy figure of 2.490 J/kg·m (3,450 BTU/ton·mile)[92] and assuming that chlorine is produced in Portland and transported an average of 80 km (50 miles), the direct energy required to deliver the 1,800,000 kg of chlorine annually is about 360 MJ, many times less than that required to produce it. For this reason, transport energy costs were not investigated further.

Treatment plant sludge quantities --- The OSU WRRI survey did not include any questions about treatment plant sludges. Except for some spotty information regarding sludge digester operation that is reported monthly to the DEQ, few data exist in this area. Therefore, a textbook[93] approach to this problem was used. Table 23 summarizes the assumptions used. Using these assumptions, which checked fairly well with actual figures at six plants investigated, total municipal sludge production averaged about 130,000 kg (300,000 lbs) per day and amounted to approximately 800,000 m^3/year (650 acre ft/year). The majority of this material was applied to open fields; the remainder was landfilled.

Interceptor Systems

Engineers and public works personnel at several communities were contacted in an effort to gain an understanding of the cost of operating and maintaining interceptor lines. The general opinion on maintenance was that interceptor costs represented a relatively small portion of the total costs of maintaining an entire collection system. Most of the problems that arise occur in the smaller sewers and, therefore, most cleaning, inspection, and reconstruction activities are concentrated far "upstream" of the interceptor. Also the majority of the interceptors in the Basin are less than 25 years old and, in general, have required less attention than the older parts of the system. Normal 0 & M expenditures for interceptors are generally for the running of lift stations and thus depend considerably on topography and flow variation.

Interceptor maintenance --- Due to a near total lack of compiled information regarding existing sewer system parameters (length, diameter, number of lift stations, etc.), it was desired to relate maintenance cost to capital cost. An estimate of 0.4 percent of initial construction cost as an annual maintenance cost for interceptor work was ventured by one city utility representative.[94] Employing this figure on the total construction costs (adjusted to 1973-74 dollars) of the

Table 23. ASSUMED SLUDGE PRODUCTION QUANTITIES[a]

Type of sludge	kg/1000m^3	(lb/mg)
Primary-undigested	140	(1200)
Primary-digested	90	(750)
Primary & trickling filter undigested	200	(1700)
Primary & trickling filter digested	140	(1200)
Primary & activated sludge undigested	280	(2300)
Primary & activated sludge digested	170	(1400)
Lagoons-undigested	240	(2000)
Lagoons-digested	170	(1400)
Extended aeration	120	(1000)
Average specific gravity	1.02	
Average moisture content	94%	

[a] Source: reference 93.

interceptor works listed in Table A1 (see Appendix) resulted in an annual cost of about $360,000.

As a verification, the same calculation was performed on the City of Portland's system, yielding a cost of $180,000 per year. (Portland's interceptor capital costs account for one half that of the total basin.) Multiplying Portland's total collection system maintenance budget of 3.5 million dollars by the ratio of interceptor length to total system length yielded a value of $140,000 per year as compared with the $180,000 above, a reasonable check. As the total interceptor maintenance cost of $360,000 per year estimated previously equaled only 5 1/2 percent of total treatment plant 0 & M, further refinement of the procedure was not attempted.

Lift station O & M --- Just as the pumping of raw wastewater at treatment facilities requires a large amount of electrical energy, so does the operation of lift stations on collection systems. The main difference is that pump stations are much more energy intensive (less labor intensive) than treatment facilities. For example, the four lift stations which comprise Portland's interceptor pumping facilities cost approximately $200,000 per year to operate and maintain, nearly 30 percent of which was for the electrical consumption of about 14 TJ (4.0×10^6 kW·hr). (Portland has a total of 38 pump stations which required approximately 33 TJ (9.2×10^6 kW·hr) of electrical energy for a 12 month period.)

The city's two treatment plants, on the other hand, cost about $1.33 million for O & M and utilized an estimated 11 TJ (3.1×10^6 kW·hr). Thus, it can be seen that truly significant amounts of energy are required to convey waste flows to treatment facilities. It should be noted that Portland is not a "typical" Willamette Basin community. It is large, topography is varied, and most wastewaters are conveyed long distances to the city's larger treatment facility. More "typical" cities are Eugene, where pump station electrical expense, 80 percent of which is for the interceptor portion, is equal to about two-thirds that of the treatment plant, and Salem, which has no pump stations on its interceptor system.

A survey of 15 major sewerage systems, discharging to 27 treatment plants, was carried out in an effort to tie down pumping energy costs. While many cities require varied amounts of pumping in low spots in their systems, only a half dozen municipalities have large interceptor lift stations. Approximately 20 TJ (5.6×10^6 kW·hr) of electricity were utilized operating interceptor lift stations. An estimated 25 to 30 TJ (6.9 to 8.3 x 10 kW·hr) were required for the operation of all other pump stations located on the upper portions of collection systems. The sum of these two figures represents about one-tenth of a percent of the total electrical use in the Willamette Basin. Due to the difficulty of separating collection system maintenance costs, no estimate was made of lift station O & M expenditures.

INDUSTRIAL WASTEWATER TREATMENT

As stated previously, the investigation of industrial expenditures was limited to the twenty firms listed in Table 15. Information regarding 0 & M costs came from an industrial survey conducted by the OSU WRRI and personal contact with company representatives. Additional information was gathered from the EPA's Development Documents for Effluent Limitation Guidelines. As the pulp and paper industry's share of both waste discharges and expenditures is such a large portion of the total industrial contributions, a section on this industry's costs is presented below.

Pulp and Paper Industry

In each of the following categories, missing expenditure figures for specific firms were estimated using data from other companies having similar processes and waste streams.

Electricity --- Electricity accounts for nearly all of the direct energy use for end-of-the-line wastewater treatment by this industry. Consumption was analyzed and correlated to flow and pollutant removal. The following summarizes the results: 570 - 3,400 MJ/1 000 m^3 wastewater (600 - 3,600 kW·hr/mg); 4.4 - 11 MJ/kg BOD_5 removed (0.55 - 1.4 kW·hr/lb); and 1.7 - 7.4 MJ/kg suspended solids removed (0.22 - 0.93 kW·hr/lb). Total annual use for the period was about 270 TJ (75 x 106 kW·hr), an average of 0.74 TJ/day (210,000 kW·hr/day). These figures represent slightly less than four-tenths of one percent of the total electrical consumption for the Willamette Valley. Total annual electrical costs were about $340,000.

Chemicals --- The pulp and paper industry uses a variety of chemicals, mainly for neutralization and nutrient addition; only one mill, where coliform growth is a problem, chlorinates. Chemical costs totalled approximately $560,000 for the annual period.

Labor and Maintenance --- Salaries and wages were the single most expensive portion of the industry's treatment costs. The annual costs amounted to about $1,100,000, accounting for slightly more than one-third of total O & M costs. Maintenance costs totalled approximately \$440,000 for the annual period.

Total Operation and Maintenance --- Total 0 & M costs for waste stream treatment by the pulp and paper industry amount to \$3,000,000 ranging from \$1.8 to \$11/1000m³ of wastewater (\$7.0 - \$40/mg). On the basis of removals, reported costs varied from 0.55¢ to 1.4¢/kg of BOD_5 removed (2.1¢ - 5.2¢/lb) and 0.34¢ to 1.4¢/kg suspended solids removed (1.3¢ - 5.4¢/lb).

Twenty Largest Industrial Firms

The addition of O & M costs of the remaining industries shown in Table 15 to the pulp and paper industry expenditures shown above raises total annual operational costs to approximately \$3,500,000. Electricity utilization is increased to about 300 TJ per year (84 x 10^6 kW·hr/year), about 0.43 percent of the total electrical use in the Willamette Valley.

Again, it should be pointed out that these industrial figures account for expenditures made by only the twenty largest (in terms of waste discharge) firms having their own treatment facilities and outfalls. Excluded are expenditures made by smaller firms with self operated facilities. Also repeating, however, the pulp and paper and related products industry is responsible for about 85 percent of the raw industrial BOD_5 produced and about 95 percent of that discharged.

Excluded, too, are expenditures made by firms discharging to municipal systems. Industrial pretreatment costs were researched. Pretreatment at many companies is an integrated part of the process; therefore, separation of water pollution control costs is generally quite difficult. At those companies where separation of costs was possible, annual operational costs were usually many times less than the sewer charges levied by the municipality. This was expected considering the low level of treatment (e.g., screening, pH adjustment) undertaken. Due to the lack of information, it was not possible to accurately estimate total industrial pretreatment expenditures; however, it was felt that these costs would not significantly increase the 3.5 million dollar figure stated above.

FEDERAL RESERVOIRS

Total Maintenance Costs

Referring to Table 17, it is seen that in Fiscal Year 1972, 2.9 million dollars were spent for maintenance at the 13 existing federal reservoirs. Assuming that water quality control (WQC) "accounts" for 3 percent of the total, as was done in Section VII for capital costs, the WQC benefit "cost" approximately $86,000, a small amount when compared to municipal and industrial O & M expenditures.

Energy Expenditures

The direct energy required to operate and maintain the Corps of Engineers' reservoirs for calendar year 1974 amounts to about 30 TJ (6.9×10^6 kW·hr of electricity plus 4.4×10^9 BTU of refined petroleum products).[95] The 3 percent of this value attributed to WQC amounts to approximately 0.9 TJ. At the same time the eight dams with power facilities delivered approximately 7700 TJ (2.1×10^9 kW·hr) to the Bonneville Power Administration for sale to utilities.

TOTAL ENERGETIC EXPENDITURES

Just as the energy associated with the capital cost figures discussed in Section VII was evaluated employing the I-O-energy methodology, the energy embodied in operational expenditures discussed in this section was estimated in the same manner. Table 24 presents the coefficients used in evaluating the energy costs of electricity, chemicals, and maintenance items. Table 25 presents the results of applying these coefficients to municipal and industrial pollution control activities; this table also summarizes the economic and energetic expenditures discussed in this section on O & M.

One item which has been deleted from Table 25 is labor. It is questionable if the energy associated with labor expenditures should be included in the energy analyses. It can be reasoned that energy expenditures associated with labor would occur whether or not the workers were employed in water pollution control activities (or employed at all). For this reason labor energy has been deleted from this report.

Several points should be noted in reference to Table 25. One, it can be seen that industry gets more electrical energy per dollar spent than does local government. This fact points out one of the weaknesses of the I-O-energy methodology: the problem of energy pricing. In this case the model has overestimated direct electrical use by municipalities and underestimated use by industry. A second point is that the methodology has underestimated the direct energy required to make the chemicals. This is most likely because the I-O-energy model lumps many chemicals of varying energy intensiveness together in one sector; chlorine, however, requires large inputs of energy in its manufacture. A third point to be stressed is that, just as with capital expenditures, much

Table 24. COEFFICIENTS USED IN CONVERTING OPERATION AND MAINTENANCE DOLLARS TO ENERGY VALUES[a]

O & M Category	Coefficients, MJ/dollar[b]	
	Direct	Total
Electricity	585.315	832.560
Chemicals	189.518	573.160
Maintenance and repair	26.905	131.321

[a] Source: Reference 84.
electricity - sector 68.01;
chemicals - sector 27.01;
maintenance and repair - sector 12.02;
based upon 1963 dollars.

[b] 1 MJ - 948 BTU.

Table 25. COSTS OF OPERATING AND MAINTAINING THE WATER POLLUTION CONTROL FACILITIES OF THE WILLAMETTE BASIN

Facility classification[a]	O & M cost, 1963 dollars	Energy requirement, TJ,[b] via I-O-energy model		Direct energy requirement, TJ,[b] via calculation
		direct	total	
Municipal facilities				
Treatment plants				
Electricity	450,000	260	370	180
Auxiliary fuel	c	c	c	33
Chemicals	240,000	46	140	69-85[d]
Maintenance and repair	1,200,000	33	160	e
Interceptors, total 0 & M	270,000	c	c	c
Interceptor lift stations				
Electricity	f	c	c	20
Industrial facilities				
Treatment plants				
Electricity	250,000	150	210	300
Chemicals	420,000	79	240	c
Maintenance and repair	740,000	20	97	e
Reservoirs				
Total				
Electricity	f	c	c	25.0
Petroleum	f	c	c	4.6
Total 0 & M	2,400,000	c	c	29.6
3% WQC				
Electricity	f	c	c	0.75
Petroleum	f	c	c	0.14
Total 0 &M	71,000	c	c	0.89

[a] As defined; see text for full description,

[b] 1 TJ = 948 x 10^6 BTU = 278 x 10^3 kW·hr.

[c] Not estimated.

[d] Energy to produce chlorine only.

[e] Does not apply.

[f] Not available.

energy is embodied or sequestered in materials. This fact is shown in comparing the direct and total energy coefficients listed in Table 24.

SECTION IX

DISCUSSION

GENERAL

The costs of water quality control facilities are generally measured in economic terms alone. The uses of natural resources, such as energy, and the net impact of treatment technologies on the total physical environment (i.e., the land, air, and water) are rarely evaluated. As a consequence of this approach to environmental management, some problems have been and are being created in pursuit of water quality objectives.

The research previously discussed dealt with identifying those facilities that are primarily responsible for maintaining high quality in the waters of the Willamette Basin, evaluating the environmental impact of the restoration of water quality, and estimating the economic and energetic costs of the cleanup.

Two major reasons for the restoration are identified in investigating the Basin's water quality control facilities. One is the reduction of oxygen demanding substances released in the river and its tributaries. A series of point-source wastewater treatment tactics, that culminated in 1972 with all dischargers employing secondary or higher levels of treatment, is responsible for this reduction. The second is flow augmentation from a network of reservoirs operated by the Corps of Engineers. Average summer flows are now more than twice the levels that occurred prior to the construction of the first impoundment.

The many environmental effects of the restoration are wide ranging. The improvement in water quality is beneficial to river organisms such as fish and is also aesthetically pleasing to both recreationalists and persons residing near the river. There are also negative impacts associated with the cleanup; one example being the loss of free flowing streams when reservoirs are constructed. Such impacts and the "tradeoffs" inherent in environmental protection programs are discussed in Section VI.

EXPENDITURES

The results of the sections regarding capital and operation and maintenance expenditures are summarized in Table 26. Capital costs have been adjusted to 1974 dollars so that a comparison with 0 & M costs is

Table 26. SUMMARY OF EXPENDITURES FOR WATER POLLUTION CONTROL IN THE WILLAMETTE BASIN.

Facility classification[a]	Capital expenditures: Construction cost, 1974 dollars	Capital expenditures: Energy requirements, TJ[b], via I-O-energy model approach: Direct	Capital expenditures: Energy requirements, TJ[b], via I-O-energy model approach: Total	Operation and maintenance expenditures, 1973-1974: O&M cost, 1974 dollars	Operation and maintenance expenditures, 1973-1974: Energy requirements, TJ[b], via I-O-energy model approach: Direct	Operation and maintenance expenditures, 1973-1974: Energy requirements, TJ[b], via I-O-energy model approach: Total	Operation and maintenance expenditures, 1973-1974: Calculated direct energy requirement, TJ[b]
Municipal facilities							
Treatment works	160,000,000	680	9,200	6,400,000	260[c]	370[c]	210[d]
Interceptors	88,000,000	380	5,100	360,000	e	e	e
Interceptor Lift Stations	e	e	e	e	e	e	20
All facilities	260,000,000	1,100	15,000	e	e	e	e
Industrial facilities	73,000,000	310	4,200	3,500,000	150[c]	210[c]	300
Reservoirs							
Total	1,100,000,000	4,800	65,000	2,900,000[f]	e	e	30
3%-WQC[g]	32,000,000	140	1,900	86,000[f]	e	e	0.9

[a] As defined; see previous sections for full description of facility classification.

[b] 1 TJ = 948×10^6 BTU = 278×10^3 kW·hr.

[c] Electrical energy only; see Table 18.

[d] 85% electricity and 15% auxiliary fuels.

[e] Not estimated; see text for discussion.

[f] Fiscal Year 1972.

[g] 3% allocated for water quality control.

Note: Energy values via I-O-energy methodology are based upon 1963 dollars.

possible. The reader should use caution, however, in comparing the capital and O & M costs of municipal treatment facilities. First, as stated in Section VII, a portion of the capital costs, accounting for about two percent of all treatment plant capital costs, are for plants which are no longer operating. Secondly, many cities have wholely or partially replaced treatment works at some point in time. No estimate of the importance of this problem was made. These two considerations are very minor in municipal collection and industrial abatement and non-existent in regards to reservoirs.

It can be deduced from Table 26 that if the direct construction energy requirements of municipal and industrial treatment facilities are amortized over a ten to twenty year life span, the resulting values are relatively small when compared to the yearly O & M needs. Amortizing the total capital energy needs of treatment works over the same period yields figures which are large in comparison to the same annual O & M needs. Thus, two conclusions are reached. First, direct energy requirements are not sufficient data on which to base the energy impact of constructing a project. Second, efforts to reduce the energy impact of these facilities could be aimed at both the construction and operational phases.

Due to their capital intensive nature, even the direct construction energy requirements of reservoirs, when amortized over a minimum life of 100 years, are important.

This research project did not address itself to evaluating total sewerage system costs. To give the reader some perspective on this subject, Table 27 presents a breakdown of sewerage costs for five municipalities. It is evident that pumping costs, particularly energetic costs, are important factors to be considered in any wastewater management plan.

It can also be seen that the upper portions of collection systems require significant maintenance expenditures. However, very little research was done on these "upstream" portions for two reasons. First, the gathering of capital cost data would have been extremely difficult due to the extremely long time span over which sewerage systems have been built. Secondly, it can be argued that the collection system above interceptors was built primarily for public health reasons and would exist whether or not interceptors and treatment works, built primarily for water pollution abatement, were constructed.

The energy costs of the water pollution abatement facilities of the Willamette Basin should be compared to total Basin energy use. In 1973, approximately 150,000 TJ of energy in the form of electricity and natural gas (petroleum excluded) were used in the Valley. Comparing this figure to the direct energy figures in Table 26 indicates that water quality control has required relatively small investments in energy resources. This is true for both capital costs, considering that the facilities have been built over a 30 to 40 year period, and operating costs. Total

Table 27. OPERATION AND MAINTENANCE COSTS OF WASTEWATER COLLECTION AND TREATMENT IN FIVE SELECTED CITIES.

City	Annual treatment costs			All collection lines maintenance cost, dollars	All pump station O&M cost, dollars	Lift station electrical energy requirements, TJ[a]	
	Dollars	Electrical energy, TJ[a]	Auxiliary Fuel energy, TJ[a]			All lift stations	Interceptor lift stations
Portland[b]	1,330,000	11[c]	d	3,500,000	470,000[e]	33	14
Salem[b]	520,000	14[c]	1.3	350,000[e]	80,000[e]	d	none
Eugene	280,000	5.4	0.12	d	d	3.6	3.1
Albany	280,000	9.7	1.1	100,000	d	0.47	0.27
Corvallis	130,000	5.0[c]	0.18	120,000	23,000	0.61	0.47

[a] 1 TJ = 948×10^6 BTU = 278×10^3 kW·hr.

[b] Two plants.

[c] Estimated, knowing unit cost.

[d] Not available.

[e] Estimated.

operational electricity, the major energy need, amounts to 0.7 percent of that used in the Basin.

This is not to say, however, that pollution control plans should be made without regard to the resource allocation required for the plan's various facilities. On the contrary, the increasingly stricter effluent guidelines proposed by regulatory agencies for all dischargers will greatly increase the energy and material requirements for water quality control. Advanced treatment processes (i.e., post-secondary treatment) are, in general, highly energy intensive. According to Hirst,[96] high level advanced waste treatment processes can more than double the electrical requirements of typical activated sludge systems. On top of this must be added large increases in chemicals and other fuels.[97] For this and other reasons, the resource implications of future environmental protection actions must be carefully considered.

It is increasingly important, in this day of awareness regarding resource limitations, that environmental protection programs yield a net improvement to our land, air, and water surroundings, while having a minimum depleting impact upon our stores of natural resources.